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Visual and Field-of-View Evaluation of the M-43 Protective Mask with Prescription Eyepieces

By

John K. Crosley

Clarence E. Rash

and

Richard R. Levine

Sensory Research Division

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United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

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The U.S. Army Aeromedical Research Laboratory was requested by the proponent of the M-43 aviator protective mask to conduct a laboratory study of the visual performance of eight AH-64 Apache helicopter pilots wearing masks with "glue-on" prescription lenses. In response, several visual functions tests were conducted including: high and low contrast visual acuity, heterophoria, fixation disparity, and stereopsis at both near and far. In addition, visual field losses of the Integrated Helmet and Display Sighting System were examined. Performance in the corrective mask was compared to that with habitual correction, either spectacles or contact lenses. The results of the visual functions tests indicated acceptable performance on all the measures except fixation disparity. The high degree of variability found on this test suggested problems associated with the

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prescription lens optical design, namely its high radius of curvature and its additional thickness. Field-of-view results indicated losses in visual field above those obtained with spectacle correction, but comparable to that found with the plano mask. Further development and testing are recommended.

25 to FLD 18

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Introduction

The AH-64 Apache is the Army's most recently fielded attack helicopter and its most advanced air combatant to date. Its operational requirements include quickly concentrating antitank and suppressive firepower on targets during day, night, and/or adverse weather conditions. To achieve its missions, the Apache employs the Integrated Helmet and Display Sighting System (IHADSS), an advanced electro-optical display system that integrates video from forward-looking infrared sensors on the nose of the aircraft with flight and weapons control symbology and presents it all to the pilot's right eye.

Central to the Apache's display system is the Helmet Display Unit (HDU), the helmet-mounted optical tube containing the miniature (1-inch) cathode ray tube (CRT) upon which the video mix is presented (Figure 1). Imagery from the CRT is relayed optically through the HDU and reflected off the combiner lens, a beamsplitter which is situated adjacent to the pilot's cheekbone and directly in front of his eye. The system is designed to provide the pilot with a 30 degree vertical by 40 degree horizontal monocular field-of-view (FOV).

Because of the limited eye relief distance between the eye and HDU, precise positioning of HDU's exit pupil is critical for full field viewing. Additional devices, such as the standard aviator's spectacle frame or his M-24 protective mask, inserted into this constricted space increase the HDU's designed vertex distance and reduce the pilot's FOV. FOV losses, in turn, impair the pilot's ability to see the flight symbology presented in the display's periphery.

To alleviate HDU compatibility problems inherent in the design of the current M-24 protective mask, the U.S. Army Chemical Research, Development and Engineering Center (CRDEC), at the direction and sponsorship of Product Manager for Aviation Life Support Equipment (PM-ALSE), has developed the M-43 protective mask for Apache aviators. This mask consists of a full-face bromobutyl/rubber molded faceblank with molded polycarbonate lenses that conform closely to the shape of the eyes (Figure 2). Both eyepieces share the same design except the right lens is notched to facilitate proper positioning of the HDU. A series of sized interpupillary distance staples is used to adjust the lenses for proper optical centering. A blower system is used to provide the mask with filtered air for breathing assistance, evaporative head cooling, and lens defogging.

Because of the mask's form-fit design, the spectacle wearing (ametropic) aviator can no longer wear the standard forms of optical correction under his mask. Therefore, CRDEC also has developed a new prescription carrier for the M-43 mask, a separate polycarbonate corrective lens that can be bonded

Figure 1. Pilot wearing the Apache aviator's helmet with the Helmet Display Unit (HDU) attached.

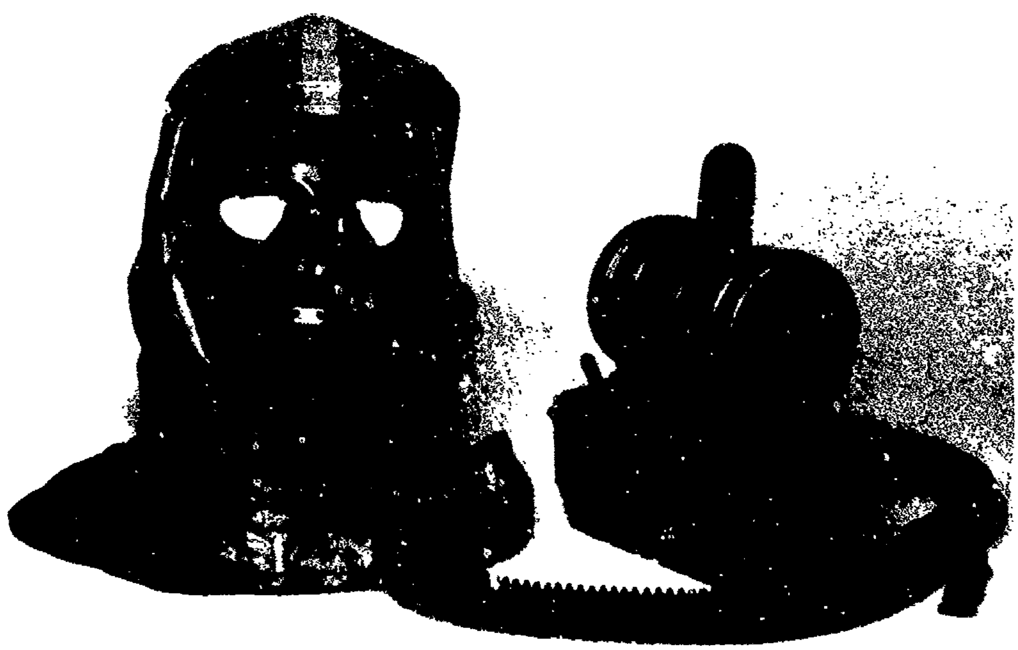

Figure 2. M-43 protective mask ensemble.

directly onto the outer surface of the eyepiece (Figure 3). Because the "glue-on" cannot be removed without great difficulty, this corrective option essentially dedicates the modified protective mask to a particular individual.

Results of optical and visual testing have demonstrated generally satisfactory visual performance with the plano (noncorrective) M-43 mask, providing the mask's blower system is functioning properly (Walsh, Rash, and Behar, 1987; Levine, Lattimore, and Behar, 1990). However, some of the mask's physical features have been reported to restrict pilot head movement and impair his visual field-of-view (Rash et al., 1984; Davis and Smith, 1989). Special concern exists with respect to the corrective lens because its added thickness (2 to 3 mm) and relatively steep (2.4 cm) radius of curvature may potentially induce visual and perceptual problems. Such problems include magnification effects (increased perceived image size), FOV reductions, and, from prismatic displacement, apparent image movement. As yet, only preliminary testing has been accomplished with the corrective mask.

To address these concerns, PM-ALSE requested that the U.S. Army Aeromedical Research Laboratory evaluate visual function and FOV through the M-43 protective mask with prescription eyepieces (Appendix A). In response, the Laboratory conducted a study designed to compare several aspects of visual function and IHADSS FOV in ametropic aviators corrected "normally" (by spectacles or contact lenses) and during wear of the corrective M-43 mask. The work was performed just prior to and in conjunction with an operational evaluation of the mask in the same subjects by the U.S. Army Aviation Development Test Activity, Fort Rucker, Alabama (Davis and Smith, 1989).

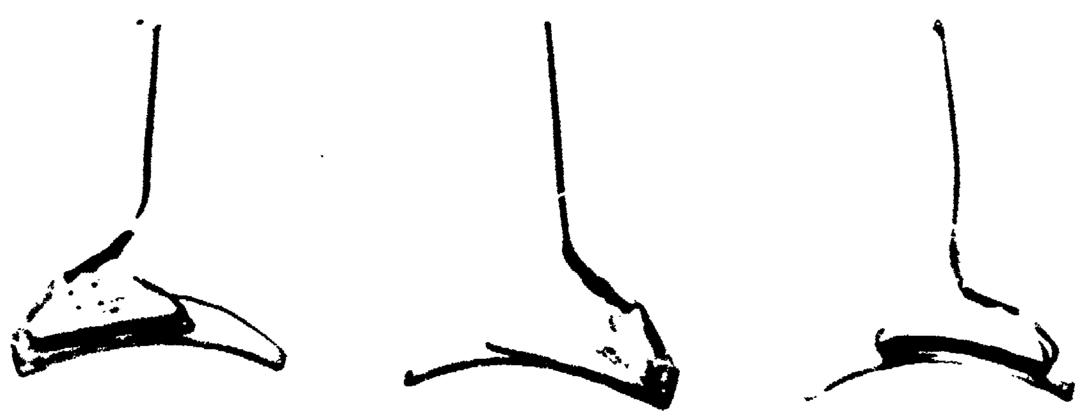

Figure 3. "Glue on" corrective optics for M-43 mask.

Methods

Subjects: Initial plans called for 15 ametropic AH-64 helicopter pilots to serve as volunteer subjects. However, for a variety of reasons, only eight could participate. Of these, six routinely wore standard flight spectacles and two wore contact lenses as participants in another study. (In the present study, both spectacles and contact lenses are considered the pilots' "normal" correction.) All were on active flight status and assigned to AH-64 battalions at Fort Hood, Texas. Responsibilities for subject selection, test scheduling, and travel funding were undertaken by PM-ALSE.

Masks and mask fitting: M-43 masks, ranging in size from small to extra large, were provided by CRDEC. Prior to corrective lens modification and subject testing, the masks were fitted individually to each subject by an aviation life support equipment specialist trained expressly for this task by CRDEC. In addition, prior to testing, each subject was provided with ample wearing time to help him adapt to the corrective mask. Subjects wore their personal helmets with the mask.

Refractive error: The use of corrective eyepieces requires that each lens pair be produced individually to match each aviator's prescription. However, because the M-43's corrective optics are manufactured by injection molding technology, fabricating a mold for every required prescription would be prohibitively expensive. Therefore, USAARL was requested to develop a prescription matrix to limit the number of required lens molds yet establish a corrective capability to provide aviators falling within this prescriptive envelope with satisfactory correction. This "compromise" prescription matrix is shown in Appendix A. (Note that the lens manufacturer is not yet capable of providing correction beyond the limits shown in this matrix [more than 1.50 diopters of hyperopia, more than 2.00 diopters of myopia, and/or more than 2.00 diopters of astigmatism].)

Prior to testing, each subject's ophthalmic prescription was validated by optometric examination. Each prescription then was compared to the prescription matrix and the "best" available power for that individual determined. This information (Appendix B) then was provided to both the mask proponent and the developer who had the lenses fabricated and permanently installed onto the proper size mask.

Visual functions tests and procedures: Several measures of visual function were selected for analysis, including high and low contrast visual acuity, heterophoria, fixation disparity, and stereopsis at both near and far. Tests first were conducted with normal correction (corrective spectacles or contact lenses) and then with the corrective mask. The test procedures were as follows:

1. High and low contrast visual acuities -- High contrast visual acuity was measured using standard (high contrast) Snellen letters projected onto a screen at a distance of 20 feet. Both monocular and binocular acuities were tested in five different directions of gaze: straight ahead, and 15 degrees each, right, left, up, and down. (Fifteen degrees was chosen arbitrarily on the assumption that a moving target will elicit a head turn after the eyes have moved some 15-20 degrees away from the primary line of sight.) Right and left gaze positions were accomplished by rotating the examining chair 15 degrees in the direction opposite to gaze; up and down positions were achieved by using a head-mounted inclinometer to position the subject's head in the desired (opposite) direction. Low contrast visual acuity was determined with the 3 and 9 percent Regan low contrast letter charts (Regan and Niema, 1983). Both monocular and binocular performance were evaluated at the recommended (10 foot) distance, but in the straight-ahead viewing position only. Subjects received one of each test with normal correction and the mask.

2. Heterophoria -- Heterophoria refers to the tendency of the two eyes to deviate from the lines of sight required to maintain single binocular vision. During testing for heterophoria, each of the eyes observe dissimilar images, thereby precluding the normal fusional process. Since the stimulus for fusion is no longer available, the eyes assume a "position of rest." The term used to describe this deviation is the "prism diopter," which is a unit specifying the amount of deviation of light by an ophthalmic prism. One prism diopter is the equivalent of bending light one centimeter at a distance of one meter. The Armed Forces vision test apparatus was used to measure heterophoria in the present study. Subject performance was determined as the mean of three trials.

3. Fixation disparity -- Although several types of disparity exist, fixation disparity may be considered as a measure of the slight over- or underconvergence of the two eyes while viewing a single target. The Wesson Fixation Disparity Card was used to determine fixation disparity in the present study.

In this test, the subject viewed a target at the normal reading distance of 16 inches. Although the subject viewed the target binocularly, polarizing spectacles were worn so that each received independent images. The subject's left eye viewed a series of chromatic vertical lines located above a single horizontal line. Simultaneously, his right eye viewed a single vertical black line below the horizontal line. The subject then was tasked with selecting the chromatic vertical line best aligned with the black vertical line. For the five linear possibilities, the corresponding fixation disparities were 4.3, 8.6, 17.2, 25.8, and 34.4 minutes of arc. A total of three

trials were administered to each subject under each viewing condition; the mean was used as the measure of his performance.

4. Stereopsis -- Stereopsis may be defined as the visual perception of three dimensional space resulting from the slightly different angle which each eye observes a target. (Stereopsis can be experienced using binocular vision only.) This sensation of "3-D" is most perceptible at distances of up to about 3 feet, although it can be demonstrated at ranges much further away. In the present study, stereopsis was measured for both near and distance vision. At reading distance (16 inches), stereopsis was tested with a single administration of the Randot stereotest. At distance (20 feet), a modified Howard-Dolman apparatus was used. (In this test, the observer aligns two vertical rods, located side-by-side, in a frontoparallel plane. The rods are enclosed in a box to eliminate extraneous depth cues, but are partially visible through the front of the box via a small, rectangular window. Instead of using the usual pulley-and-cord arrangement to move the rods back-and forth [a technique that can introduce unwanted tactile and proprioceptive cues to the desired visual task], the device was modified so that rod movement was controlled electronically and signalled remotely via a hand-held radio controller.) Stereopsis thresholds for each subject were determined as the standard deviation of the misalignment scores of 10 trials.

<u>IHADSS FOV test and procedures</u>: FOV testing was conducted with all but one of the spectacle wearers (Subject 2). For the remaining spectacle wearers, measurements were made first with spectacle correction and then with the corrective mask. (During FOV testing, modified spectacle frames were worn in order to accommodate the HDU [McLean and Rash, 1984].) For the contact lens wearing subjects, FOV was evaluated with contact lenses only, with contact lenses and a plano mask, and with the corrective mask. (Measuring visual fields with the plano mask permitted us to assess the effects of increased eyepiece thickness on the IHADSS' FOV.)

FOV measurements were made in the laboratory with the IHADSS. Video signals used for initial alignment and target stimuli were generated by a Hewlett-Packard model 9845B computer used in conjunction with a Tektronix 4025 terminal. Video signals were input to an IHADSS digital electronic unit, which, in turn, produced the desired visual output on the helmet-mounted CRT display. The output then was relayed optically through the HDU and finally reflected off the combiner. The raster was generated so as to match the CRT facemask on the display face. The facemask was designed so that the visible image size corresponded to a 30 degree vertical by 40 degree horizontal FOV.

Prior to testing, the subject was fitted with his helmet and the HDU. Then, he was provided with an alignment pattern,

consisting of a series of meridional lines, with which to focus, center, and orient the display imagery. A practice trial then was administered to verify the centering of his FOV and familiarize him with the test procedures.

Testing was conducted in a darkened room with the subject seated and facing a black partition. The target stimulus consisted of a small, high contrast, computer-generated tic mark which entered the subject's (HDU's) FOV along one of eight different meridians. The target progressed towards the center of the display in increments of approximately 1/8th of a degree and at a rate of two incremental steps per second. The selected meridians were at the following angles: 0, 36, 90, 144, 180, 216, 270, and 324 degrees. Figure 4 shows the relative directions of the measured meridians. (A center reference cross and a short meridional indicator line were generated for each target so as to alert the subject to the entry direction of the target.)

To determine the field extent over which the symbology could be presented, the subject was instructed to look in the direction of the entering target. Upon each detection, the subject pressed

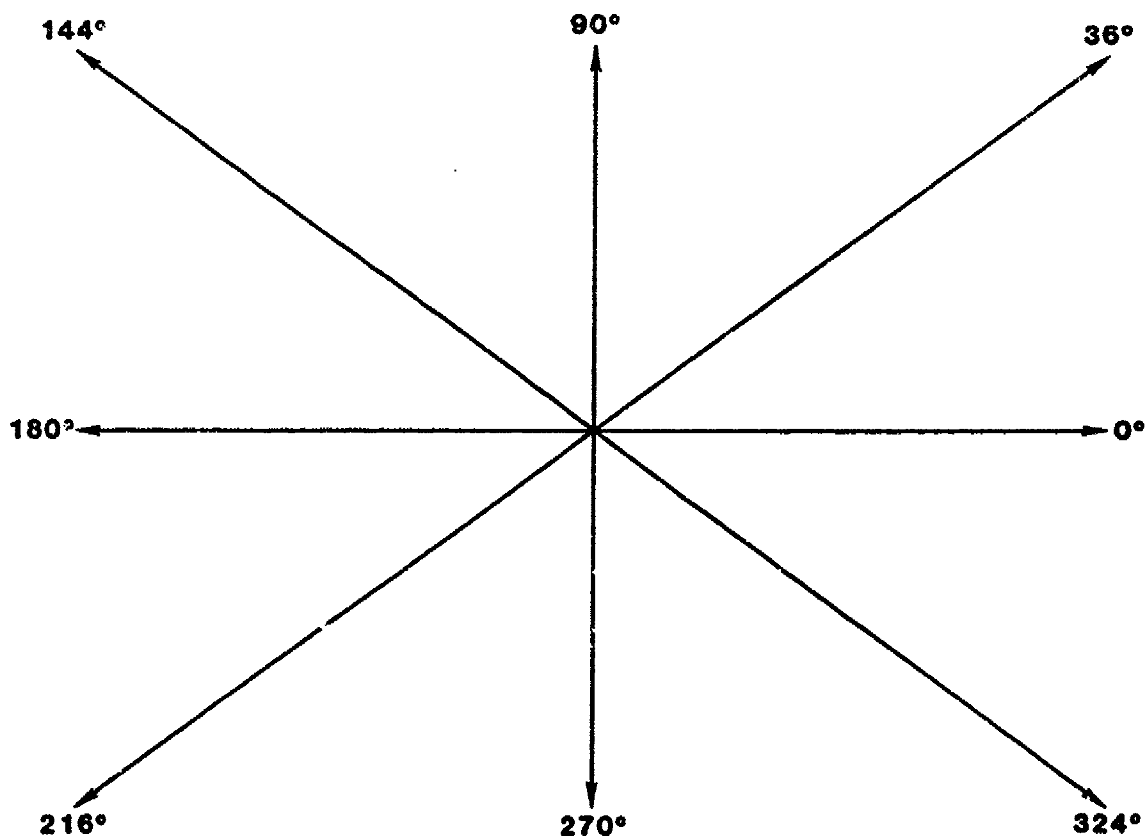

Figure 4. Meridians selected to examine HDU's field-of-view.

a hand-held switch. An audible "beep" was used as feedback for each detection. Testing consisted of four presentations along each meridian, first in a counterclockwise direction and then in reverse direction for each successive presentation. To compensate for possible learning effects, the sequence of conditions was alternated for each subject.

Results

Mask-induced visual field obstruction: It was evident from the start of acuity testing that the inherent design of the M-43 protective mask impaired binocular vision in many of the tested directions of gaze. Table 1 provides a comparison of mask obstructions reported by each subject for each tested viewing direction.

Table 1.

Directions of gaze blocked by the M-43 protective mask

	Right eye position (degrees)				Left eye position (degrees)			
Subject	15 up	15 down	15 left	15 right	15 up	15 down	15 left	15 right
1	**				**			
2			*					**
3	**		**		**			**
4	**		**		**			**
5	**		**	*	**		*	**
6			**				*	
7			**					**
8			**					**

* Denotes partial blockage
** Denotes complete blockage

As can be seen, half the subjects reported complete visual obstruction with an upward viewing angle of 15 degrees. (Even a slight upward gaze required compensatory head movement to achieve binocularity.) Most subjects, because of blockage by the nasal profile, also reported complete visual interference in the right eye looking 15 degrees to the left and, in the left eye, looking 15 degrees to the right. While not addressed in this study, our observations also indicate that there will likely be some subjects who encounter difficulty with binocularity at distances closer than 20 inches; the degree of physical interference with vision will be dependent upon the aviator's facial features and the fit of the mask.

Visual functions tests:

1. Visual acuity: Due to the viewing problems associated with the mask, the proposed test matrix for high contrast acuity could only be partially completed. As shown in Table 1, complete high contrast acuity testing could be achieved only for the straight ahead and downward gaze positions. However, comparable results were obtained, for both monocular and binocular vision, at all nonobstructed positions of gaze.

Table 2 presents the high contrast acuity results for the straight-ahead viewing condition. These data are considered representative for all the tested directions of gaze. For comparison purposes, the data are broken out according to habitual visual correction -- spectacles or contact lenses. Treatment means are shown in Snellen notation to facilitate their interpretation. (The means were calculated by obtaining the values of the logarithms of the minimum angles of resolution, averaging them, and then converting them into their Snellen equivalents. The positive and negative numbers adjacent to the Snellen values represent, respectively, the number of additional letters identified correctly on the next smaller line of the chart or the number of letters missed on the "best" line read.)

Table 2.

Mean high contrast Snellen acuity for straight-ahead gaze

Viewing Condition	Eye(s) Right	Left	Both
Normal correction			
Spectacle wearers	$20/15^{-1}$	20/15	20/15
Contact lens wearers	$20/15^{-2}$	$20/20^{+1}$	$20/15^{-1}$
Corrective mask			
Spectacle wearers	20/15	$20/15^{-1}$	20/15
Contact lens wearers	20/20	$20/20^{+1}$	$20/15^{-1}$

As can be seen Table 2, high contrast letter acuity was generally 20/20 or better for all subjects under the two corrective conditions of viewing. Measured acuities were slightly better with two eyes rather than with one and in spectacle wearers rather than in contact lens subjects. However, better binocular acuity simply confirms the expected effects of binocular summation (Campbell and Green, 1965), where two-eyed acuity exceeds that with one, and the small number of subjects tested in lenses renders the slight differences in average acuity associated with the different modes of visual correction without

practical significance. More important to the objectives of the present study, these data reveal no impairment in high contrast acuity using the glue-on corrective optics.

The results of the low contrast acuity tests are shown in Table 3. Since similar performance levels were observed among spectacle and contact lens wearers, to simplify the data presentation, the data from both groups have been combined (N=8 for each viewing condition). The mean acuities are expressed to the nearest whole Snellen line.

Table 3.

Mean low contrast acuity

	9% contrast			3% contrast		
Viewing condition	Right eye	Left eye	Both eyes	Right eye	Left eye	Both eyes
Normal correction:	20/25	20/25	20/20	20/40	20/40	20/30
Corrective mask:	20/30	20/30	20/25	20/40	20/40	20/30

As expected, acuities were generally better with the higher contrast chart and with two eyes rather than with one. (No differences in mean acuity between fellow eyes were observed.) Small differences between the two viewing conditions were observed, but only on the 9 percent chart. While these differences occurred in several subjects, the magnitude of the effect (on the average 3 or 4 chart letters) is too small to be of practical significance.

2. Heterophoria -- Average horizontal heterophoria (esophoria) was 1.49 prism diopters for subjects wearing their normal correction (spectacle mean=1.55; contact lens mean=1.32) and 1.08 prism diopters with the corrective mask. Neither the amount of measured esophoria nor the differences observed with each corrective system are considered to be of practical significance.

3. Fixation disparity -- Fixation disparity for subjects in spectacles ranged from 0 to 5.73 minutes of arc (min arc) exophoric (exo; overall mean = 1.67 min arc); disparities for the two contact lens wearers were 2.87 and 8.60 min arc exo, respectively. In corrective masks, the eight subjects displayed much greater variability. Mean disparity (and numbers of subjects) for the corrective mask condition were: 0 min arc (2), 4.3 min arc exo (1), 7.16 min arc exo (1), 8.6 min arc exo (1), 25.8 min arc exo (1), 5.73 min arc esophoric (eso) (1), and 8.6 min arc eso (1). The overall mean with the corrective mask was 3.94 exo. Among just the spectacle wearers, one subject remained 0, two

creased in exo, and three increased in eso -- a wide response distribution with no apparent trend.

The high degree of variability in disparity among subjects in the corrective mask suggests the presence of prismatic displacement. Causative candidates include the mask lens's high radius of curvature, its added thickness, or its nonoptical centering during assembly. Binocular deviation in fixation disparity could result in each case even with very small, off-center positions of viewing. Follow-up optical testing is necessary to resolve whether the design parameters of the M-43's prescription optics or its assembly process are problematical.

4. Stereopsis -- Stereopsis at near distance with the Randot test showed no significant differences among viewing conditions. Average angular disparity thresholds measured 25.9 sec arc for subjects with normal correction versus 23.44 sec arc with the corrective mask. Performance by contact lens wearers fell within the performance envelope exhibited by the spectacle wearers.

Stereopsis at distance with the Howard-Dolman device was more variable. Without the mask, mean angular disparity thresholds were 8.72 sec arc for spectacle wearers and 8.68 sec arc for the two contact lens wearers. Mean disparity among the eight subjects increased to 24.01 sec arc when they made the same observations through the corrective mask. Examination of the data showed this rather large figure to be the result of the data from the first two subjects tested. Eliminating the corrective mask data from both subjects reduced the mean to 5.49, an improvement over the observations made through habitual correction.

<u>IHADSS field-of-view</u>:

1. Corrective mask vs. modified spectacles: Individual field-of-view plots were made for each of the subjects tested. Two of these plots, representing "best" and "worse" case results among the spectacle wearers, are shown in Figures 5 and 6. In each figure, the bold, outer rectangle represents the designed 30 X 40 degree IHADSS design field-of-view. The inner curves represent the measured visual fields for each of the viewing conditions tested. The dotted curve represents the subject's field with modified corrective spectacles and the solid curve represents his field with the M-43 corrective mask. As can be seen, field losses along the horizontal and oblique meridians generally exceeded those obtained vertically (but see below). More important, field losses with the corrective mask exceeded those with the modified spectacle.

A critical factor which can affect field size along any given meridian is the alignment of the HDU. For example, misalignment along the horizontal axis can result in both a measured

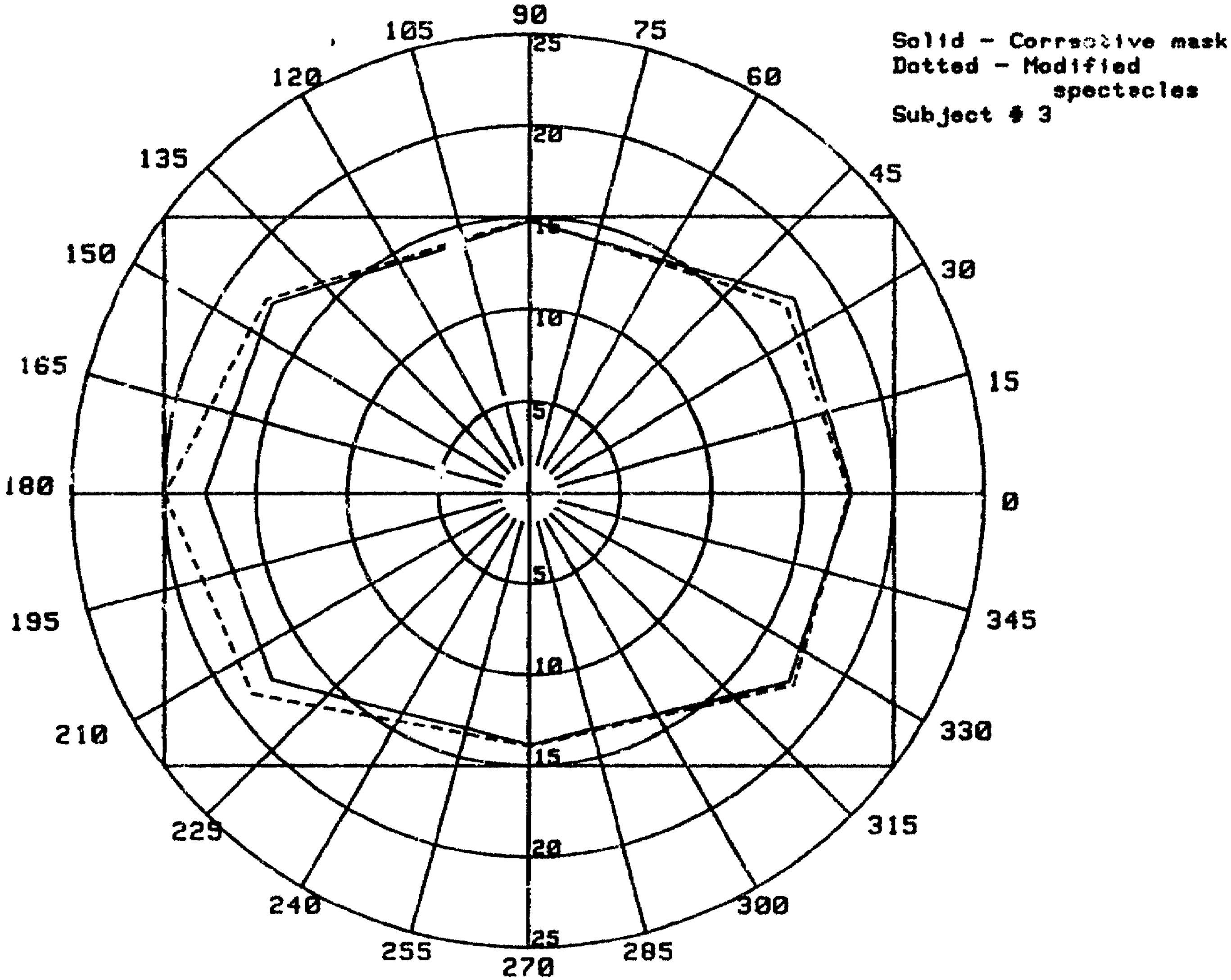

Figure 5. "Best case" IHADSS FOV with M-43 corrective mask and corrective spectacles (Subject 3).

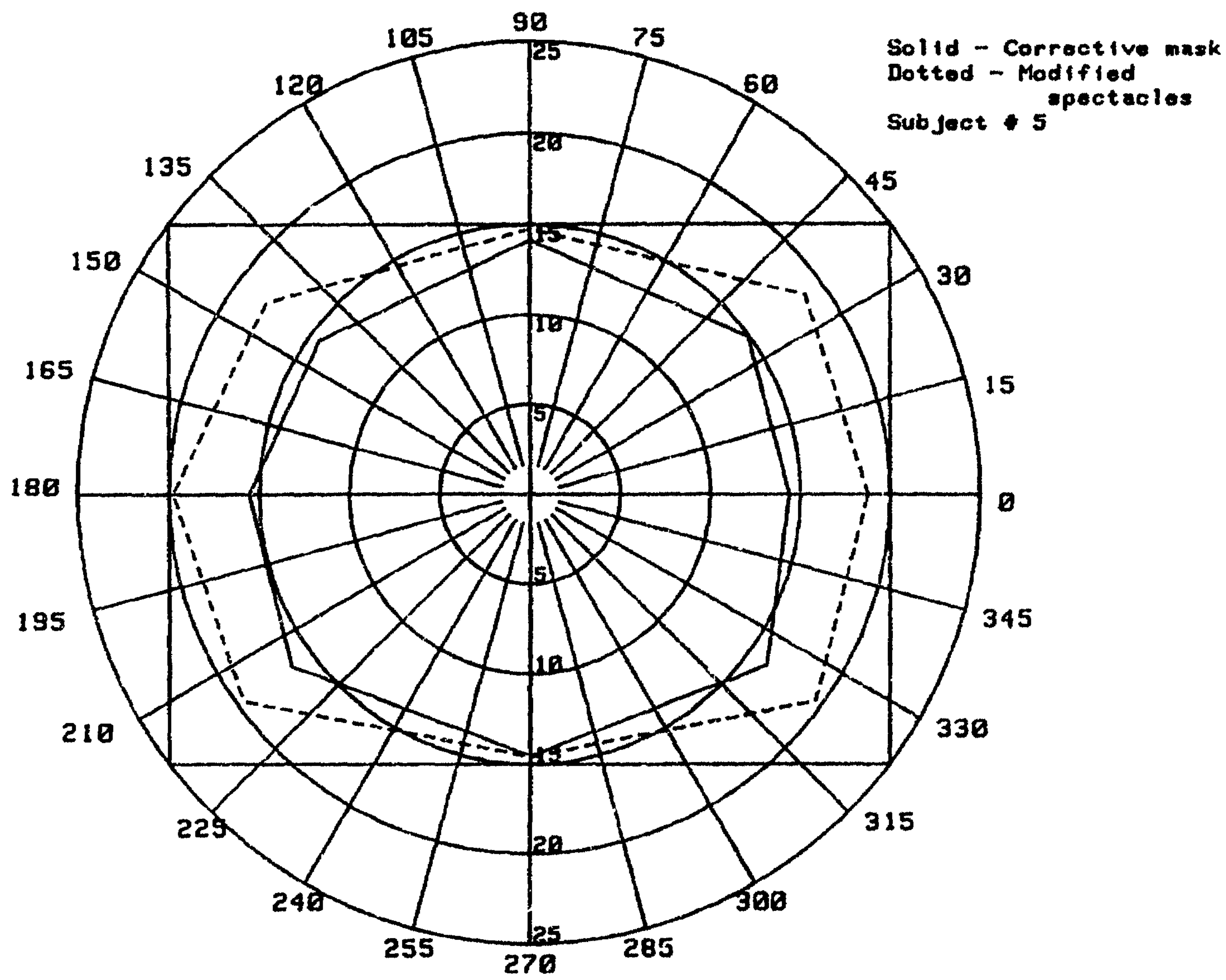

Figure 6. "Worst case" IHADSS FOV with M-43 corrective mask and corrective spectacles (Subject 5).

field decrease along the 0 degree meridian and a corresponding increase along the collinear 180 degree meridian. To "correct" for this effect, data from pairs of collinear meridians (0 and 180, 36 and 216, 90 and 270, and 144 and 324 degrees) were used to compare field losses in the two viewing conditions. Table 4 presents the summed field measurements for both the corrective mask and modified spectacle conditions.

Table 4.

Collinear meridional fields for spectacle wearers (in degrees): Corrective mask vs. modified spectacles

Meridians:	0 + 180		36 + 216		90 + 270		144 + 324	
Conditions:*	CM	MS	CM	MS	CM	MS	CM	MS
Subj. 3	35.5	36.5	35.4	36.1	28.6	28.8	35.1	35.7
4	30.5	37.0	29.8	36.6	28.5	29.0	29.4	36.4
5	30.0	38.5	31.2	38.5	28.7	29.4	30.7	37.7
7	32.3	35.7	34.8	37.4	29.4	29.6	33.1	32.8
8	33.5	39.1	33.7	38.4	29.2	29.6	32.6	38.3
Mean	32.4	37.4	33.0	37.4	28.9	29.3	32.2	36.2
Range	5.5	3.4	5.6	2.4	0.9	0.8	5.7	5.5
SD	2.25	1.41	2.40	1.07	0.40	0.36	2.21	2.15

* Conditions: CM = Corrective mask; MS = Modified corrective spectacles.

As shown in Table 4, vertical field loss with the corrective mask was greater than vertical field loss with modified spectacles by an average of just 0.4 degrees (28.9 vs. 29.3 degrees or 1.4 percent). However, horizontal field loss with the mask exceeded spectacle field loss by 5 degrees (32.4 vs. 37.4 degrees or 13.2 percent.)

Because of the limitations on the vertical field (maximum of just 15 degrees on each side), actual losses along the vertical meridians may be underestimated and a straightforward average of values across all meridians may be misleading. A better figure of merit for quantifying field sizes and losses associated with each viewing condition is the average of the means for the two diagonal meridional pairs (36 + 216 degrees and 144 + 324 degrees). For the five subjects tested under the conditions of corrective mask and of modified spectacles (no mask), the average field of the diagonal collinear pairs decreased from 36.8 to 32.6 degrees, or 11.4 percent.

The percent values given above represent the percentages of reduction along a given meridional pair. As quoted, they do not

represent the percentage of field-of-view lost. However, if the available field-of-view is assumed to be somewhat circular in shape, then the average values of the two diagonal meridional pairs approximate the diameters of the fields. Based on these assumptions, the typical field area for the condition of the modified spectacles is 1064 square degrees. The associated area for the condition of corrective mask is 824 square degrees, a reduction of 23 percent.

2. Corrective mask vs. plano mask: Figure 7 presents a representative field plot for one of the two lens wearers. Again the solid curve shows the subject's FOV with the M-43 corrective mask, but in this figure the dotted curve indicates the visual field with a plano mask worn together with contact lenses. Table 5 presents the collinear meridional fields for the two conditions.

Table 5.

Collinear meridional fields for contact lens wearers: Corrective mask vs. plano mask w/lenses

Meridians:	0 + 180		36 + 216		90 + 270		144 + 324	
Conditions:*	CM	PM/C	CM	PM/C	CM	PM/C	CM	PM/C
Subj. 1	30.0	30.4	29.5	31.1	28.9	29.3	29.4	30.5
6	32.4	34.5	32.3	34.0	29.5	29.5	32.4	33.7
Mean	31.2	32.5	30.9	32.6	29.2	29.4	30.9	32.1
Range	2.4	4.1	2.8	2.9	0.6	0.2	3.0	3.2
SD	1.70	2.90	1.98	2.05	0.42	0.14	2.12	2.26

* Conditions: CM = Corrective mask; PM/C = Plano mask + contact lenses.

As can be seen, a comparison of visual field losses from the two masks showed minimal differences. The mean loss along the vertical collinear meridional pair was 0.2 degree or 0.7 percent; the mean loss along the horizontal collinear meridional pair was 1.2 degrees or 3.7 percent. Comparing field size using the two diagonal meridians indicated a 4.6 percent decrease with the corrective mask to 30.9 from 32.4 degrees. This translates into an additional 9 percent FOV reduction with the prescription eyepieces, a difference which may be too small to be of practical significance. However, further testing with additional subjects must be conducted to determine the reliability of corrective vs. plano mask differences before definitive conclusions can be drawn.

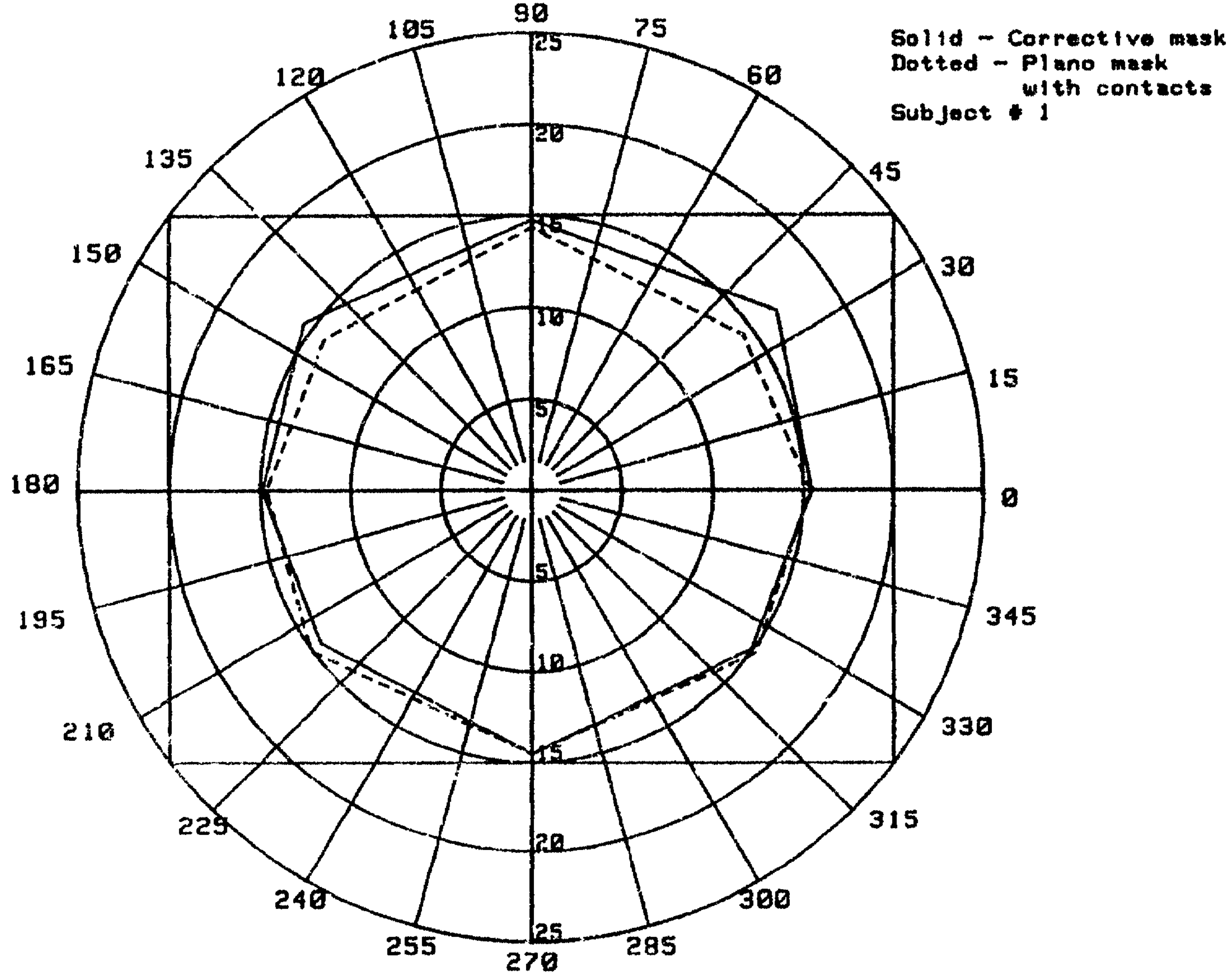

Figure 7. Comparison of IHADSS FOV with corrective and plano masks (Subject 1).

Discussion and conclusions

The present study was designed to assess several aspects of visual performance in ametropic AH-64 aviators wearing the prototype M-43 corrective mask. Performance on a number of visual functions tests (including high and low contrast visual acuity, heterophoria, fixation disparity, and stereopsis) were evaluated in the corrective mask and with the aviator's normal means of visual correction (spectacles or contact lenses). In addition, the use of glue-on prescription eyepieces was compared to both spectacles and the plano mask with respect to additional losses in the HDU's field-of-view. The study was conducted on eight subjects, six spectacle wearers and two contact lens wearers, a sample much smaller than that anticipated originally. Thus, while our study results are informative and useful, conclusions based on these data presently must be considered tentative.

The results of the visual functions test were mixed. Comparable and satisfactory visual performance was achieved with both spectacle and contact lens correction and with the corrective mask for high and low contrast acuity, heterophoria, and stereopsis. Measurements of fixation disparity, however, showed considerable variability, even with slight off-axis angles of viewing. This variability seems most likely due to the unwanted prism power associated with the glue-on's thickness and high radius of curvature. Subjects also reported (and we observed) the presence of image magnification, in all likelihood, resulting from the lens' optical design and/or assembly. Finally, problems associated with mask fit and facial characteristics may have also contributed to the study results. To ensure optical centering and avoid prismatic imbalance and subsequent visual discomfort, procedures must be developed to ensure accurate fit, both initially and long-term, of the corrective M-43 mask.

No significant differences in FOV loss were observed between the corrective mask and the plano mask, although the data showed general mask-related impairments in binocular vision in the 15-degree upward and lateral directions of gaze. However, the results of the study showed a greater IHADSS FOV loss with the corrective mask relative to that observed with modified corrective spectacles (a reduction in area of about 23 percent). A major consequence of the M-43's reduced field-of-view will be its impact on the visibility of the IHADSS symbology. Measurements of the imagery on the IHADSS indicate the symbology is located within a field of 29 degrees vertical by 34 degrees horizontal. It is noteworthy that six subjects (86 percent) failed to obtain this field-of-view when wearing the M-43, either corrective or plano.

Nonresearch issues. Prior to selection of the glue-on lenses as the method of choice to correct ametropic M-43 mask

wearers, there are a number of nonresearch issues that need to be addressed. These include, but are not limited to, the following:

a. The fit of the M-43 mask is heavily dependent upon facial configuration. Asymmetrical features can contribute to the introduction of optical problems. For example, if the wearer's eyes are not level, adjusting the mask to compensate may be impossible. Should the wearer have a relatively large face combined with a narrow interpupillary measurement, even the most narrow interpupillary distance staple may be insufficient to adjust the eyepieces properly, a situation virtually assuring prismatic imbalance and visual discomfort.

b. The glue-on lenses dedicate the mask to one individual.

c. This method of correcting ametropia is quite expensive, especially if the decision is made to provide the wearer with a spare mask. The spare would likely be required, especially if the soldier was assigned overseas.

d. Should the mask or mask eyepieces need to be replaced for any reason (such as a prescription change), it would have to be accomplished by a CONUS contractor. The Department of Defense optical laboratories currently do not have the capability of supporting this program. Because of the technical requirements and the expense, it is unlikely they would ever be able to provide such support.

e. Presently, there is no way to verify the eyepiece prescriptions once they are mounted in the mask. This is not likely to change, since there is no known commercial optical instrument that has this capability.

f. The use of a prescription matrix limits the number of lens combinations available to users. It would be absolutely necessary to expand the current matrix, should the glue-on lenses become the system of choice.

g. Because of the large number of possible combinations, premanufactured stocked lenses would not be feasible. It is more likely their fabrication would be by "demand," possibly requiring a considerable amount of acquisition or replacement time.

Recommendations

The results of this study indicate adequate visual performance with the M-43's prescription optics within the limits of the laboratory environment. However, additional optical and visual testing must be performed before this corrective system can be recommended without reservation for operational use. Particular misgivings exist with the high degree of measured fixation

disparity among the subjects tested. In the course of a flight this level of inaccuracy could generate noticeable visual discomfort in the wearer. While we encourage the further development and testing of this prescriptive technique, our results indicate the effects of undesirable design problems, assembly problems, or both in these prototype optical samples. Initial operational testing by Davis and Smith (1989) confirms these and other visual problems as well.

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Appendix A

PM-ALSE request memorandum

DEPARTMENT OF THE ARMY
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REPLY TO ATTENTION OF

AMCPM-ALSE-D

26 May 1987

MEMORANDUM FOR: Commander, U.S. Army Aeromedical Research Laboratory, ATTN: SGRD-UAS-VS, P.O. Box 577, Fort Rucker, Alabama 36362-5292

SUBJECT: M43 CB Mask Optical Correction Evaluation

1. Reference letter, SGRD-UAS-VS, 28 April 1987, subject: Visual Correction with the M-43 Protective Mask.

2. Evaluation of the adequacy of optical correction in M43 CB Mask lenses remains a critical issue to be resolved. Your letter, referenced above, suggests two testing schemes to complete the evaluation. The first consists of laboratory testing on the matrix of lenses. We will attempt to obtain masks with the complete matrix as rapidly as possible to begin this effort, after reviewing the research outline you will provide.

3. The second scheme involves in-flight testing. Coordination has begun with TECOM, USAAVNDTA, and the 6th CBAC (Ft Hood) to schedule this testing for the ten aviators who will receive prescription lenses in their masks. The 6th CBAC has tentatively agreed to conducting the test from 8 thru 12 June 1987. An outline of the proposed test, to be monitored by the USAAVNDTA, is at encl 1.

4. Agreements reached at the Pre-IPR on 22 April 1987 stated that a checkride with a Standardization Instructor Pilot (SIP) was required for flight clearance for aviators with optically corrected lenses. The proposed test scheme expands this concept to collect additional data.

5. Request you review the outline and provide recommendations for possible inclusion by 29 May 1987. Your recommendations should consider that we are constrained, to some degree, by the availability of time within the field unit and funds.

6. The ALSE PMO point of contact is Tom Hrastich, AUTOVON 693-3210 or commercial 314-263-3210.

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CDR, CRDEC, SMCCR-PP

Appendix B

M-43 prescription matrix

Sphere matrix [actual]	Cylinder matrix [actual]
+1.00 [+0.97]	0.00 [-0.02]
+1.00 [+0.97]	-0.75 [-0.78]
+1.00 [+0.97]	-1.50 [-1.53]
+0.50 [+0.56]	0.00 [-0.02]
+0.50 [+0.56]	-0.75 [-0.78]
+0.50 [+0.56]	-1.50 [-1.53]
Plano [+0.03]	0.00 [-0.02]
Plano [+0.03]	-0.75 [-0.78]
Plano [+0.03]	-1.50 [-1.53]
-0.50 [-0.41]	0.00 [-0.02]
-0.50 [-0.41]	-0.75 [-0.78]
-0.50 [-0.41]	-1.50 [-1.53]
-1.00 [-0.85]	0.00 [-0.02]
-1.00 [-0.85]	-0.75 [-0.78]
-1.00 [-0.85]	-1.50 [-1.53]
-1.50 [+1.37]	0.00 [-0.02]
-1.50 [+1.37]	-0.75 [-0.78]
-1.50 [+1.37]	-1.50 [-1.53]
-1.87 [Proposed]	0.00
-1.87 [Proposed]	-0.75
-1.87 [Proposed]	-1.50

Appendix C

Subject prescriptions for the M-43 glue-on optics

Subject	Prescribed Rx OD/OS	Mask Rx OD/OS *
1	-1.50 -0.25 x 70	-1.37 Sphere
(CL)**	-1.50 -0.25 x 90	-1.37 Sphere
2	Plano -1.50 x 90	+0.03 -1.53 x 90
	Plano -0.75 x 70	+0.03 -0.78 x 70
3	-0.75 -0.75 x 100	-0.85 -0.78 x 100
	-0.75 -0.75 x 95	-0.85 -0.78 x 95
4	+0.75 -0.75 x 137	+0.56 -0.78 x 137
	+0.50 -0.75 x 57	+0.56 -0.78 x 57
5	+1.50 -0.50 x 172	+0.97 Sphere
	+1.25 -0.50 x 03	+0.97 Sphere
6	-0.25 -0.25 x 05	-0.41 Sphere
(CL)	-1.00 -0.25 x 10	-0.85 Sphere
7	+0.25 -0.50 x 105	+0.03 -0.78 x 105
	+0.75 -1.50 x 72	+0.56 -1.53 x 72
8	+1.25 -1.00 x 100	+0.97 -0.78 x 100
	+1.25 -1.25 x 85	+0.97 -0.78 x 85

* Source: American Optical Company, Southbridge, MA
** CL: Contact lens wearer

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Dr. Christine Schlichting
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Box 900, NAVUBASE NLON
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